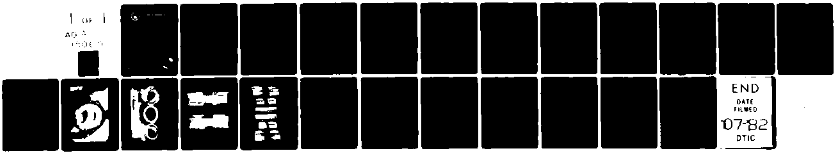
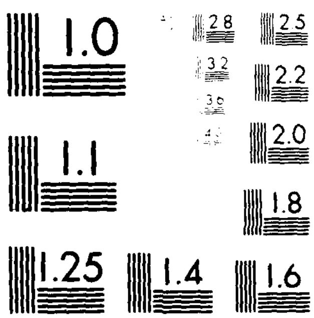
AD-A115 060 NAVAL AIR ENGINEERING CENTER LAKEHURST NJ F/G 13/7
APPLICATION OF WEAR DEBRIS ANALYSIS TO AIRCRAFT HYDRAULIC SYSTE--ETC(U)
MAY 82 P V CIEKURS, S A ROPAR
UNCLASSIFIED NAEC-92-158 NL





MICROCOPY RESOLUTION TEST CHART

(12)

NAVAL AIR ENGINEERING CENTER

REPORT NAEC-92-158

LAKEHURST, N.J.
08733

APPLICATION OF WEAR DEBRIS ANALYSIS TO AIRCRAFT HYDRAULIC SYSTEMS

Advanced Technology Office
Support Equipment Engineering Department
Naval Air Engineering Center
Lakehurst, New Jersey 08733

10 MAY 1982

Technical Report
AIRTASK A03V3400/051B/1F41461000

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION UNLIMITED

Prepared for

Commander, Naval Air Systems Command
AIR-340E
Washington, DC 20361

NAEC-92-158

APPLICATION OF WEAR DEBRIS ANALYSIS TO AIRCRAFT HYDRAULIC SYSTEMS

Prepared by: P.V. Ciekurs
P. V. Ciekurs, P.E.
Advanced Technology Office (92A3)

Approved by: F E Evans
F. E. Evans
Support Equipment Engineering Superintendent

NOTICE

5-10-82 10A

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NAEC-92-158	2. GOVT ACCESSION NO. AD-A115060	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) APPLICATION OF WEAR DEBRIS ANALYSIS TO AIRCRAFT HYDRAULIC SYSTEMS		5. TYPE OF REPORT & PERIOD COVERED Technical 6. PERFORMING ORG. REPORT NUMBER NAEC-92-158
7. AUTHOR(s) P. V. Ciekurs S. A. Ropar *		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Air Engineering Center Advanced Technology Office (92A3) Lakehurst, NJ 08733		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AIRTASK A03V3400/051B/1F41461000
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Air Systems Command AIR-340E Washington, DC 20361		12. REPORT DATE 10 May 1982 13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

* North American Aircraft Division/Rockwell International Corporation
Columbus, Ohio

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

WEAR DEBRIS ANALYSIS
OIL ANALYSIS
FERROGRAPHY
TRIBOLOGY

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents an investigation into the feasibility of applying wear debris analysis methods as a maintenance tool for aircraft hydraulic systems. A breadboard was designed and operated, fluid samples were analyzed and trended. No relevant failures were experienced and limited conclusions reached. Recommendations are made for further investigations.

PREFACE

This report documents an exploratory investigation into the feasibility of applying wear debris analysis technology to monitor the wear state of an aircraft hydraulic system. This was a coordinated effort between the North American Aircraft Division (NAAD) of Rockwell International Corporation at Columbus, Ohio, and the Naval Air Engineering Center (NAVAIRENGCEN) Tribology Lab, Lakehurst, New Jersey. NAAD was responsible for the design, fabrication, and operation of the breadboard under contract N68335-80-C-0520 and NAVAIRENGCEN performed the fluid analysis. This work was sponsored by the Naval Air Systems Command, AIR-340E, under the Maintenance Technology Block Program.

This page left blank
intentionally

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

I. INTRODUCTION

A. BACKGROUND.

1. The contamination of hydraulic systems has been a major cause of concern over the past two decades. This resulted in the initiation of a multitude of programs aimed at studying contamination and its effect on hydraulic systems. Contamination is defined as any foreign material that may adversely affect the performance and reliability of hydraulic systems. This material is not limited to solid particulates, but also includes foreign liquids and gasses.

2. The main thrust in past Navy programs, has been in the area of contamination control aspects of hydraulic fluid analysis. Current measurement techniques include patch testing (primary method), automatic particle counters, halogen leak detectors, and to a much lesser extent spectrometric oil analysis. Most of these techniques result in the classification of particulates into quantities of particle size ranges, which are then compared to standards. Based on these comparisons, it is determined whether the system requires cleaning.

3. Another aspect of the analysis of hydraulic fluid is the detailed analysis of the entrained wear debris. Studies (references (a) and (b)) have demonstrated that by a detailed analysis of various wear debris parameters, a determination can be made as to the state of wear in an oil-lubricated system.

B. OBJECTIVE. The objective of this investigation was to determine the feasibility of using wear debris analysis to determine the state of wear in an aircraft hydraulic system.

II. EXPERIMENTAL PROCEDURES

A. TEST APPARATUS DESCRIPTION.

1. The generation of wear-debris-laden fluid samples was accomplished by the construction of a breadboard of an aircraft hydraulic system. The system consisted of those components that were considered to be the most wear prone based on historical experience. The components were arranged in such a fashion as to simulate the actual operational characteristics of each specific component.

Ref: (a) D. Scott, W. W. Seifert, V. C. Wescott; "The Particles of Wear", Scientific American; May 1974, Vol 230, No. 5, pages 88-97.
(b) V. C. Wescott, "Predicting and Determining Failures by Means of Ferrography", paper given at Ninth Annual FAA International Aviation Maintenance Symposium, Washington, DC

2. The test system was constructed utilizing actual aircraft components from the recently decommissioned RA-5C. The RA-5C's hydraulic system is representative of the hydraulic systems of aircraft currently in the operational inventory; therefore, conclusions applying to the breadboard are valid for actual aircraft.

3. The breadboard consisted of a piston pump, three actuators (a landing gear actuator, dual yaw actuator, and a horizontal stabilizer actuator), control valves, reservoir, and filters. Figure 1 is a schematic diagram of the test apparatus configuration; the figure also identifies the locations of the sampling parts and temperature and pressure monitors. Table 1 is an itemized listing of components identified in Figure 1. Each actuator was provided a loading, simulating the loads experienced during normal operations. The only deviation from an actual aircraft system was the use of 25-µm filter elements in lieu of the 5 µm used in current aircraft systems.

4. The system fluid was a fire resistant synthetic hydrocarbon conforming to MIL-H-83282. Tubing was stainless steel and aluminum with standard flareless tube connections with gasket seals.

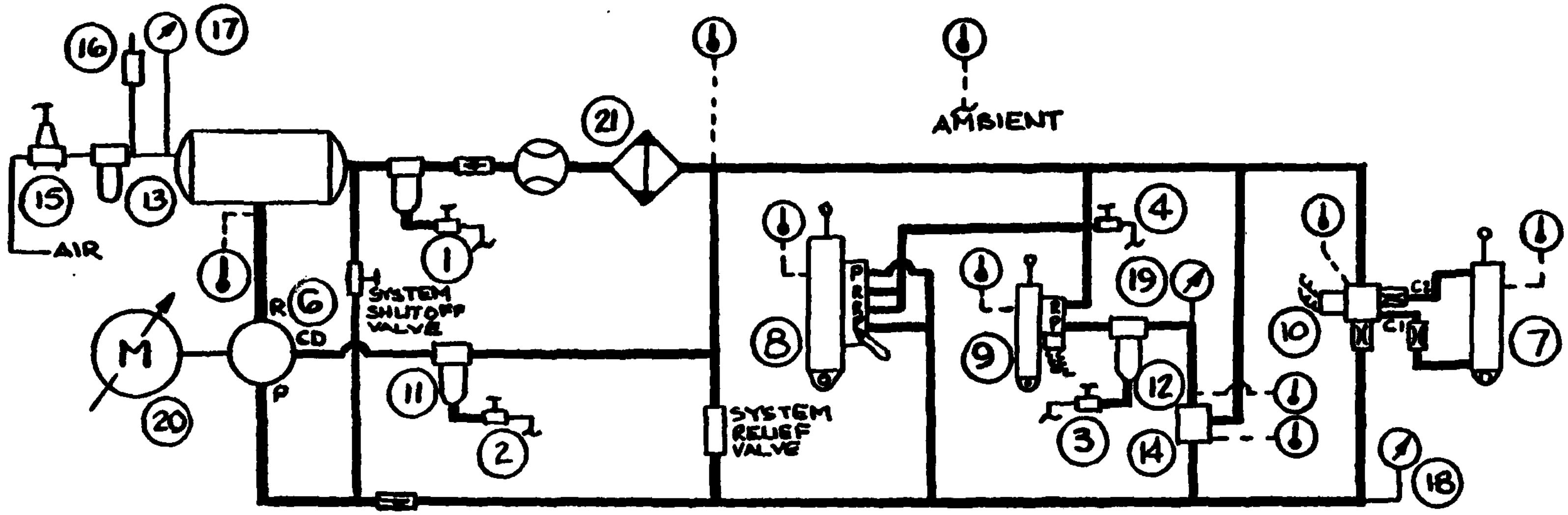
B. TEST APPARATUS OPERATION.

1. The test system was operated in a laboratory room environment where the system ambient temperature was nominally 80°F. The reservoir temperature was maintained at the arbitrary temperature of 150°F.

2. The test system pressure and temperature parameters were nearly constant during the entire test endurance cycling. The drive unit for the pump was selectively set at 2000 rpm. This speed provided a longer pump piston stroke than would normally be experienced for the lower flow demands, 2.4 to 4.6 gpm, of this smaller system. The longer piston stroke by the reduced pump speed, produced near full pump piston travel which more closely simulates the higher flow demands of pump capacity (15 gpm), and higher pump speed in an actual aircraft system. The test temperatures typical during cycling were as follows:

Location	Typical Test Temperatures (Deg. F)
System Return	170
Pump Suction	150
Dual Yaw Actuator	125
Horizontal Actuator	162
Landing Gear Actuator	155
Landing Gear Valve	160
Pressure Reducer Output	155
Pressure Reducer Body	135
Ambient-Test Setup	80

Operational pressures were constant throughout the test operation and are noted on Figure 1.



NOTE: NUMBERED ITEMS ARE IDENTIFIED IN TABLE I.

Figure 1 - Schematic of 3000-psi Laboratory Test System

TABLE I
LABORATORY TEST COMPONENTS

*ITEM	COMPONENT	DESCRIPTION
1	LAB ITEM	FLUID SAMPLING POINT #1 (FILTER-RES. SYS. RETURN)
2	LAB ITEM	FLUID SAMPLING POINT #2 (FILTER-PUMP CASE DRAIN)
3	LAB ITEM	FLUID SAMPLING POINT #3 (FILTER-DUAL YAW ACTUATOR)
4	LAB ITEM	FLUID SAMPLING POINT #4 (SYSTEM-RETURN LINE BLEED)
5	AIRCRAFT	RESERVOIR - HYDRAULIC FLUID (AIR-OIL)
6	AIRCRAFT	PUMP - HYDRAULIC, 15 GPM AT 3000 PSI RATING
7	AIRCRAFT	ACTUATOR - LANDING GEAR, 3000 PSI
8	AIRCRAFT	ACTUATOR - HORIZONTAL FLIGHT CONTROL, 3000 PSI
9	AIRCRAFT	ACTUATOR - DUAL YAW, ELEC. SERVO INPUT, 1500 PSI
10	AIRCRAFT	VALVE - LANDING GEAR, SOLENOID OPERATED
11	AIRCRAFT	FILTER - PUMP CASE DRAIN
12	AIRCRAFT	FILTER - DUAL YAW ACTUATOR CIRCUIT
13	AIRCRAFT	FILTER - RESERVOIR AIR PRESSURE
14	AIRCRAFT	PRESSURE REDUCER - 3000 to 1500 PSI
15	LAB ITEM	REGULATOR - AIR PRESSURE, RESERVOIR
16	LAB ITEM	VALVE - AIR PRESSURE RELIEF, RESERVOIR OVERPRESSURE
17	LAB ITEM	GAGE - AIR PRESSURE, RESERVOIR
18	LAB ITEM	GAGE - HYDRAULIC PRESSURE, SYSTEM (3000 PSI)
19	LAB ITEM	GAGE - DUAL YAW ACTUATOR CIRCUIT (1500 PSI)
20	LAB ITEM	POWER UNIT - VARIDRIVE, 25 HP
21	LAB ITEM	HEAT EXCHANGER - SYSTEM RETURN FLUID (WATER COOLED)

* ITEMS SHOWN IN FIGURE 1.

3. The test system accumulated a total operational time of 681.5 hours. Table 2 depicts the relationship between the operational time and the qualification time for component endurance life. In most cases the operational time was in excess of the design life of the component.

TABLE 2 - TEST COMPONENT CYCLE SUMMARY

COMPONENT	RATE (cycles/min)	TOTAL TEST CYCLES	QUALIFICATION CYCLES
Hydraulic Pump		(681.5 Hours)	(750 Hours)
Horizontal Actuator	2.87	117,312	200,000
Dual Yaw Actuator	8.32	340,348	200,000
Landing Gear Valve	2.25	91,987	20,000
Landing Gear Actuator	2.25	37,763	20,000
Landing Gear Actuator	2.25	24,414[1]	20,000
Landing Gear Actuator	2.25	29,810[2]	20,000

[1] with replaced seals
[2] replacement actuator

4. The test system was monitored for possible component and/or fluid line leakage. The only leakage that occurred was at the dual yaw actuator piston rod end. This leakage occurred near the start of the test cycling and persisted throughout the test. The leakage rate varied from 0.06 to 0.09 cubic centimeter per minute. Since the leakage was not significant the actuator was not replaced. Sufficient fluid was initially placed in the reservoir; no fluid was added during the test program.

5. Fluid samples were extracted at each of four locations with a total of 44 samples per location. One sampling port was located in the system return line; this provided a representative sample of line flow. The other three ports were located in each of three filter bowls; one located in the pump case drain, two in the system itself. The filter bowl location provided an accumulative sample over a nominal sampling interval of about 20 hours.

C. SYSTEM FAILURE DATA.

1. Three failures occurred during the test program: a seal failure, a fatigue crack, and a tube fitting interface failure due to vibration. Even though the endurance life of the components was exceeded, there were no relevant metallic failures attributable to abnormal wear.

2. The seal failure occurred at the landing gear actuator after 37,763 cycles (279.7 hours) of operation. The seal and teflon backup ring extruded, resulting in a severely "chipped" seal and high flow leakage. The seal failure

has been attributed to a material flaw causing a material breakdown, since no abnormal condition was found at the seal mating surfaces. However, the failed seal did perform satisfactorily 190% of its qualification life. The seal was replaced and tests restarted. Photographs of the actuator and failed seal appear as Figures 2 and 3 respectively.

3. Another failure occurred in the landing gear actuator after 62,177 cycles (460 hours) of operation (24,414 cycles after seal failure). The actuator's forged aluminum head developed a hairline crack approximately 0.375 inch long. The crack appears to have originated internally at the static seal groove radius. At this time the actuator had exceeded its endurance life by over 300%; it was replaced with another actuator and testing was restarted.

4. The third failure occurred in a 3000-psi aluminum line located near the pressure reducer (Item 14, Figure 1) after 355 hours. An unusual darkening of the fluid obtained at the filter located upstream of the dual yaw actuator was noticed; subsequent investigation revealed a wear pattern in the aluminum tubing apparently due to vibration or movement between the fitting and tubing. Figures 4 and 5 illustrate the observed wear patterns. The tubing section was replaced by a stainless steel tube; no further darkening was noticed. Testing was resumed.

D. <u>WEAR DEBRIS ANALYSIS TECHNIQUES</u>.

1. Each fluid sample was analyzed for the four parameters that previous research had shown to be indicative of an abnormal wear condition. These parameters are: particle quantity, particle size distribution, morphology, and elemental composition. The analysis was accomplished through the use of analysis equipment consisting of a particle counter, atomic emission spectrometer, direct reading (DR) ferrograph, and the analytical ferrograph.

2. The analysis of metallic debris was accomplished using accepted analysis methodologies utilizing the equipment of the previous paragraph.

III. DISCUSSION OF RESULTS

A. <u>INTRODUCTION</u>.

1. The results of this effort were not as fruitful as expected, due primarily to the absence of relevant metallic failures that could be directly related to abnormal wear.

2. A substantial amount of data was generated, however, and as such, some general observations concerning the wear debris characteristics of hydraulic systems can be made.

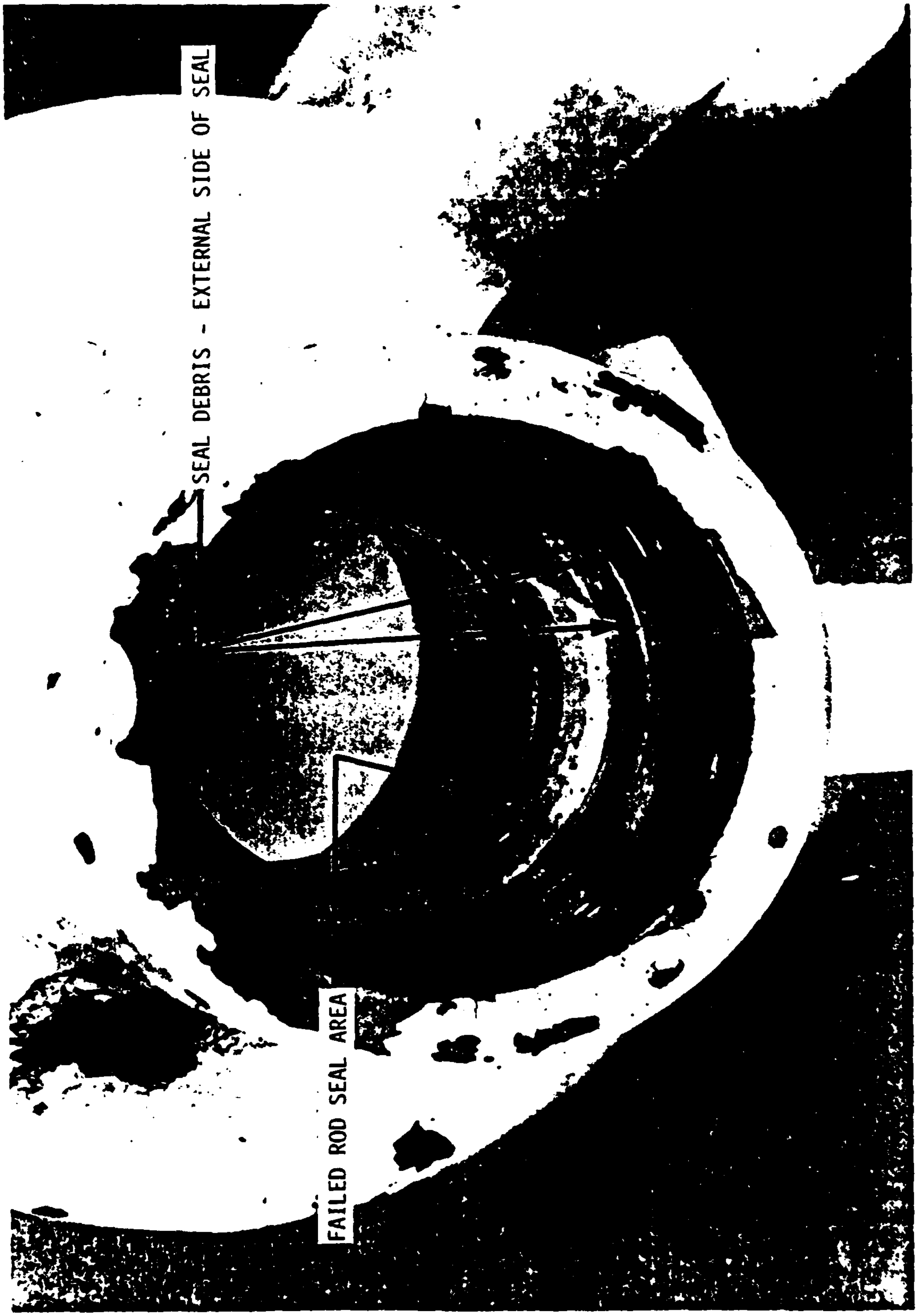


Figure 2 - Cylinder Head - Landing Gear Actuator and Backup Rings

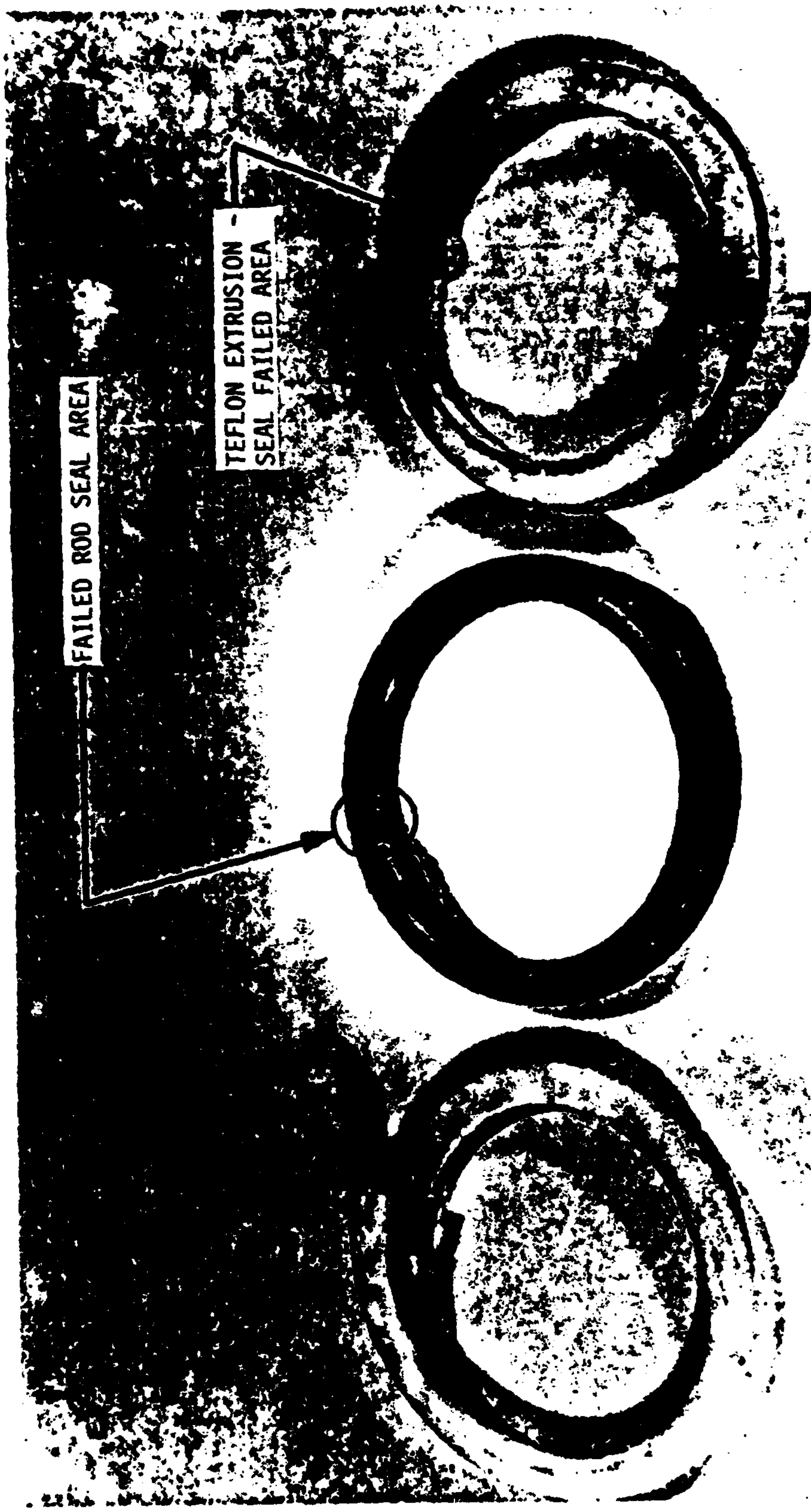


Figure 3 - Rod End Seal and Backup Rings - Close-up, Landing Gear Actuator

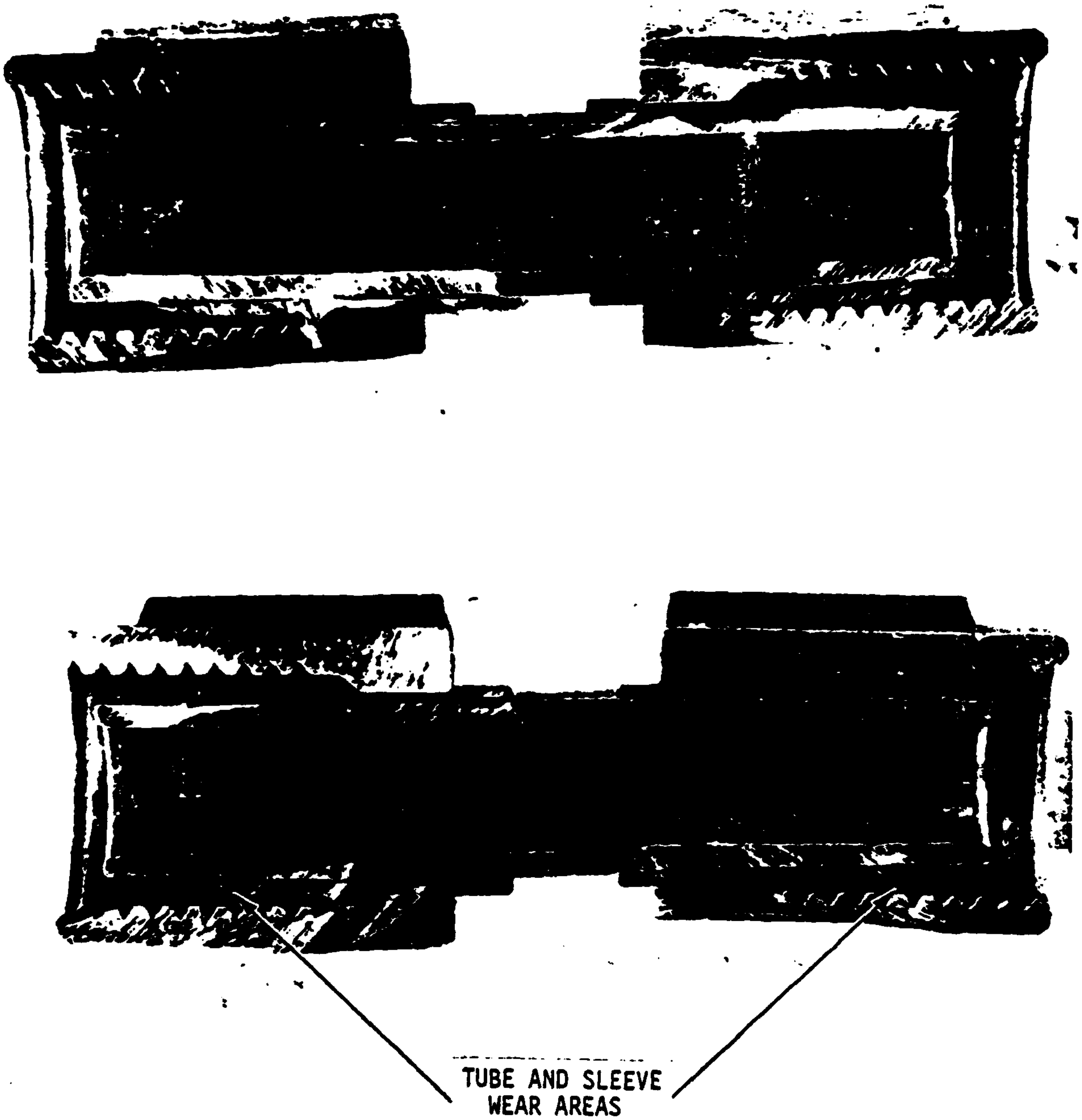


Figure 4 - Bisected Tube and Fittings

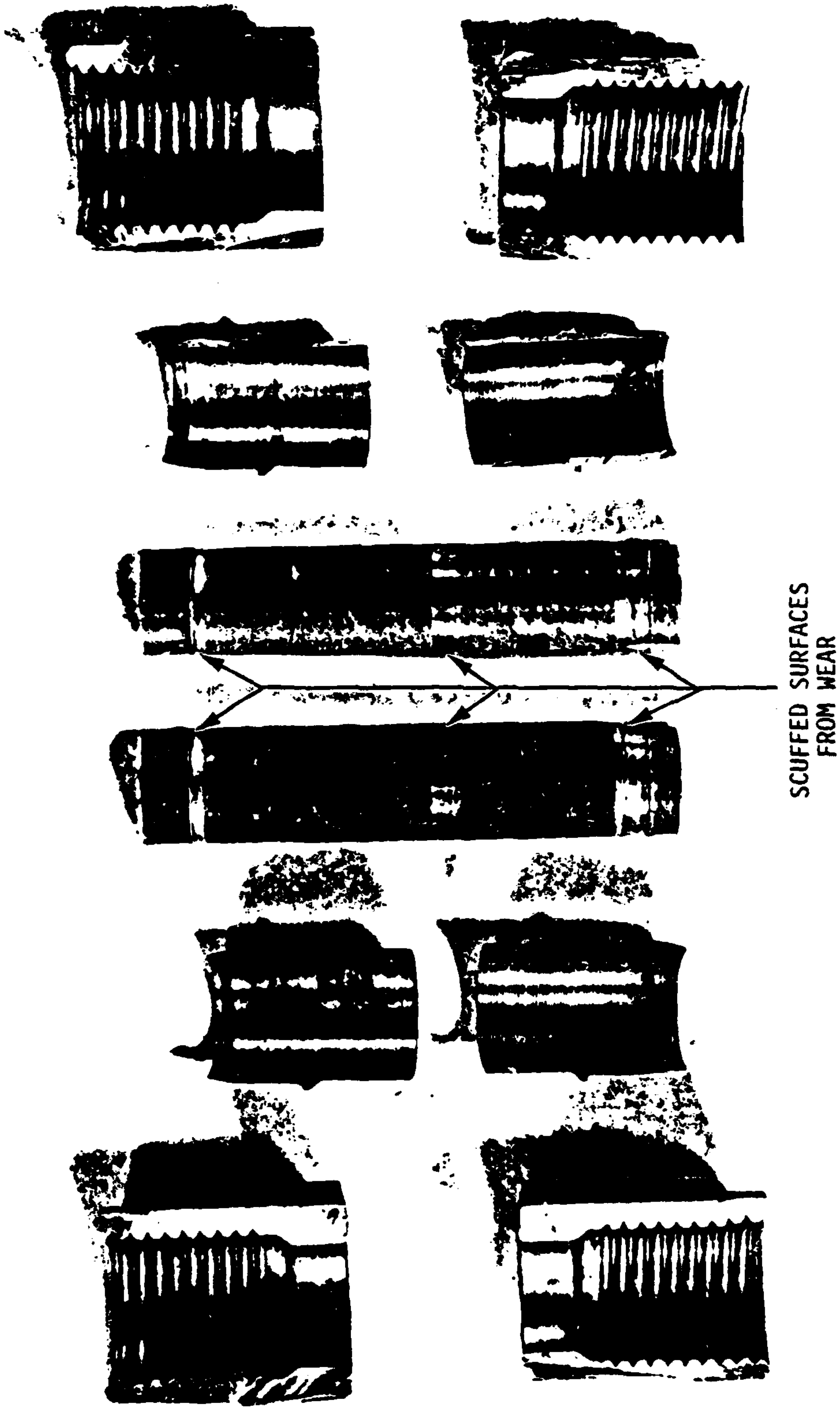


Figure 5 - Bisected Tube and Fittings - Disassembled

B. PARTICLE QUANTITY AND SIZE DISTRIBUTION.

1. Particle quantities and size distribution were monitored for each sample and location over the life of the test. Typically, it was found that particle generation quantities and size distributions were similar regardless of the particular sampling location. The majority of debris fell within the size range of 2 to 5 µm; at the early portion of the tests, this size range made up between 75 to 90% of the overall count. As time progressed, the amount of debris in this range decreased to levels between 55 and 75%. Debris generated in the size range of 5-7 µm varied between 7 and 12% throughout the test, while particles in the range of 7-15 µm varied between 7 to 10%.

2. A normal wear situation in an oil-lubricated system is usually indicated by particles below 15 µm, with the majority of these in the 2-5 µm size range. This situation also holds true for hydraulic systems as evidenced by particle quantity and size distribution data and the normal performance of the system.

3. It should be pointed out that this system incorporated filtration at a level of 25 µm, while operational aircraft hydraulic systems are filtered to 5 µm. Samples were taken from the filter bowl to allow for debris generated upstream of the filter to be analyzed prior to being lost in the filter. This resulted in the capture of a very small amount (less than 1%) of debris in the 25 µm+ category. It is therefore possible that a system filtered to 5 µm could substantially truncate debris quantities above this size range,thus making a determination as to abnormality based on quantity and size difficult if not impossible.

4. It should also be noted that these particle counts include all debris in the system,both metallic and nonmetallic.

C. ELEMENTAL COMPOSITION.

1. Another parameter of interest in wear debris analysis is the elemental composition of the wear debris. This composition was determined by the use of an atomic emission spectrometer, the same unit currently in use in the military Joint Oil Analysis Program (JOAP). Although the spectrometer identifies a total of 21 elements, it was felt that 6 of these should provide some indication of the wear state of the system. In particular the elements selected were: iron (Fe), aluminum (Al), copper (Cu), nickel (Ni), tin (Sn), and molybdenum (Mo).

2. Comparing the relative quantities of these elements between sampling locations, it was found that concentrations did not vary substantially. At all four locations,levels of nickel debris were comparable with concentrations in the range from 0 to 0.7 ppm. It was observed that nickel debris levels were higher at the beginning of the tests; as time progressed beyond the 150-hour mark, only trace amounts were periodically recorded.

3. Copper debris was also observed in relatively low concentrations. At three of the four locations, debris levels on the order of from 0.2 to 1.0 ppm were observed; at the case drain of the pump, these levels increased to 1.5 ppm between 160 and 240 hours, but then subsided to the levels found at the other locations after 240 hours.

4. Levels of molybdenum debris were found to be somewhat higher than the previously discussed elements. These levels ranged between 0.2 ppm to 10.3 ppm. In general, molybdenum debris levels at the beginning of the test cycle were lower than levels toward the end, but in some cases there were large fluctuations from one sample to the next. For example, in one instance, two consecutive samples were recorded at 9.2 ppm and 10.3 ppm, while the subsequent samples fell to 2.2 ppm and 1.3 ppm and continued along these levels for some time.

5. A trend similar to molybdenum was observed for tin. Once the levels were corrected to eliminate the tin found in the base oil, tin debris levels were found to gradually increase with time. Typical levels rose to 4.0 ppm in the first 150 hours of operation and then tended to fluctuate up and down for the remainder of the tests between 4.0 ppm and 1.7 ppm.

6. Aluminum debris levels rose with time, with some traces at the start of the tests and rising to about 4 ppm after 300 hours. After this time it appeared that the aluminum achieved somewhat of a level of equilibrium with a fractional fluctuation of ±0.3 ppm for the duration of tests. Two of the failures experienced were related to aluminum components, one the fatigue crack of an actuator and the other a mysterious darkening of the fluid thought to be related to a wear condition of the tubing. In either case, no substantial change in aluminum debris levels were observed prior to the indicated abnormalities.

7. The final element of interest was iron. Again it was found that there was no substantial variation throughout the tests. Typically, iron debris levels started somewhat higher toward the beginning of the cycling and dropped to an apparent level of equilibrium averaging about 3.0±1 ppm. One exception was the debris in the case drain that continued to increase to a peak of 14.3 ppm at 200 hours, and then subsequently subsided to equilibrium levels after 300 hours. Since the pump was operated to 91% of its design life with no performance degradation or other readily apparent problems, it is felt that this increase did not denote a problem but was an anomaly of the pump.

8. In closing it appears that wear metal concentrations tend toward some level of equilibrium in the hydraulic system. In addition, sudden change in this concentration does not necessarily indicate an impending failure; therefore, it is felt the wear metal concentration alone is not a reliable indicator of trouble in a hydraulic system.

D. MORPHOLOGY.

1. Information concerning the severity of wear of a particular piece of equipment can be gained by analyzing its morphology. It has been found that

different wear modes exhibit particles that have unique morphological characteristics (reference (c)). In this particular effort the morphological studies were performed by means of analytical ferrography. Descriptions of the ferrographic technique are common in the literature and will not be discussed here.

2. The sampling locations, with the exception of the pump case drain, exhibited similar types of particle morphologies. This is understandable since the particulate generated in the area comes from linear actuators. There were no unusual wear modes observed from these locations.

3. The pump case drain exhibited the most debris quantities. This is understandable since the case drain flow provides lubrication to the most highly stressed components of the pump, that is, the bearings and swash plate. Typically, an adverse wear mode would be identified by fatigue-related particles from the bearing or by severe sliding wear particles. Although particles of this type were not observed during this particular test, they have been confirmed in related efforts (reference (d)) and bear further investigation.

E. SEVERITY OF WEAR INDEX.

1. Another parameter which has been demonstrated to indicate the severity of a wear situation is the severity of wear index. This quantity is derived from the information supplied by the DR ferrograph. This device precipitates out the ferromagnetic debris in much the same way as the analytical ferrograph. The exception is that the debris is precipitated out within a glass tube. Two light sensors measure the blockage. The amount of light attenuation at each of two locations is indicative of the relative amount of debris. One reading denotes the amount of large debris (larger than 5 μm), and is labeled D_L. The other number is representative of small debris (1 μm to 2 μm), and is labeled D_S. The severity of wear index is derived from these units and is equal to the difference between D_L^2 and D_S^2.

2. The severity of wear indices for the system sampling locations were comparable. Typically they were high at the beginning of the tests, falling in range between 10^2 and 10^3. As the tests progressed their values fell to the range between 0 and 50 and remained there for the duration.

3. As in previous cases, the case drain samples again varied from the rest of the system. At the onset, values ranged between 500 and 1000. After 100 hours the value of the index began a steady climb, reaching a peak of 191,000 at 225 hours. As time progressed, the index again began to fall and returned to

Ref: (c) "Wear Particle Atlas"; Naval Air Engineering Center Report NAEC-92-163 (PRELIMINARY)
(d) Summary of Analysis of Wear Debris from LHS Impulse Lab Tests, 20 February 1981, NAVAIRENGCEN TRIBOLOGY LAB

the 1000 to 5000 range in a matter of 25 hours. The index slowly decayed from these levels during the remainder of the test and leveled out to a range of 100 to 500.

4. Ferrograms were prepared and analyzed over the range, where the wear index rose. The analysis revealed no unusual wear debris, but did reveal a fibrous material deposited on the ferrogram. Most likely it was this fibrous material that caused the excessive wear indices and not an abnormal wear mode. This indicates that the DR ferrograph can provide false alarms of an abnormal condition and therefore a follow-up should be performed on all unusual changes in the index.

IV. CONCLUSIONS

A. As stated earlier in this report, the results of this investigation were not as fruitful as anticipated. This is primarily due to the lack of relevant metallic component failures which could be directly related to an abnormal wear condition. Therefore, it is not possible to draw any definitive conclusions concerning the applicability of wear debris to aircraft hydraulic systems. However, it is possible to draw some generalities and to make some subjective judgments about the results.

B. The results indicate that the filter bowl can be used as a sampling location and that, depending on the system, one location could be indicative of the entire system, if properly chosen. In this instance it was the return line filter.

C. The pump case drain flow is apparently worthy of monitoring due to the amount of metallic debris available. Since this flow lubricates critical components it is worth investigating further.

D. The remainder of the system, linear actuators, valves, etc., do not produce sufficient quantities of metallic debris to make them candidates for monitoring. The majority of the components used in these tests exceeded their design lives and produced no significant change in metallic debris generation.

E. Nonmetallic components such as seals should be investigated for monitoring potential.

F. Due to the amount of nonmetallic material generated within a system, the DR ferrograph should not be the sole indicator of an abnormal wear condition.

G. Judging by the amount of metallic material generated and the reliability of these hydraulic components, it appears that it would not be cost effective to monitor the hydraulic systems of aircraft on a regular basis. This statement is based on the application of the current state of the art in wear debris analysis techniques.

V. RECOMMENDATIONS

A. Conduct further investigations of wear debris characteristics of hydraulic pumps in order to develop some baseline failure data that could be applied in a maintenance environment.

B. Investigate the wear debris characteristics of seals, to ascertain the feasibility of monitoring this debris in lieu of metallic debris. Identification of unique debris characteristics should be investigated and related back to a particular component. Unless some type of unique characteristics can be identified and related to a specific family of components, it would be futile to monitor a hydraulic system.

VI. REFERENCES

(a) D. Scott, W. W. Seifert, V. C. Wescott; "The Particles of Wear", Scientific American; May 1974, Vol. 230, No. 5, pages 88-97.

(b) V. C. Wescott, "Predicting and Determining Failures by Means of Ferrography", paper given at Ninth Annual FAA International Aviation Maintenance Symposium, Washington, DC.

(c) "Wear Particle Atlas"; Naval Air Engineering Center Report NAEC-92-163 (PRELIMINARY).

(d) Summary of Analysis of Wear Debris from LHS Impulse Lab Tests; 20 February 1981, NAVAIRENGCEN TRIBOLOGY LAB.

DISTRIBUTION LIST

NAVAIRENGCEN
1114 (2)
1115
9011
92A1C
92A3
92A31 (20)
92A4
92711

JOAP/TSC
ONR-430

NAVAIRSYSCOM
AIR-00D4 (2)
AIR-340E (3)
AIR-417
AIR-411
AIR-552B
AIR-5523 (3)

DTIC (12)

NAVAIRREWFAC, Pensacola FL
NAVAIRREWFAC, Alameda CA
NAVAIRREWFAC, Cherry Point NC
NAVAIRREWFAC, North Island CA
NAVAIRREWFAC, Norfolk VA
NAVAIRREWFAC, Jacksonville FL

REVISION LIST

REVISION	PAGES AFFECTED	DATE OF REVISION

ATE

MED

8